TECHNICAL MEMORANDUM LWL-CR-06P72D

NONSCRATCHING WINDSHIELD WIPER BLADE

by

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April 1974

Final Report

Contract DAAD05-71-C-0422

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Prepared For

U. S. ARMY LAND WARFARE LABORATORY
Aberdeen Proving Ground, Maryland 21005

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: LWL-CR-06P72D	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): NONSCRATCHING WINDSHIELD WIPER BLADE	5. TYPE OF REPORT & PERIOD COVERED: Final
	6. PERFORMING ORG. REPORT NUMBER: F-C-3120-11
7. AUTHOR(s): John W. Woestman	8. CONTRACT OR GRANT NUMBER(s): DAAD05-71-C-0422 Work Assignment No. 11
9. PERFORMING ORGANIZATION NAME AND ADDRESS: The Franklin Institute Research Laboratories, Benjamin Franklin Parkway, Philadelphia, PA 19103	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: LWL Task 06-P-72
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Land Warfare Laboratory, ATTN: AMXLW-ADP, Aberdeen Proving Ground, MD 21005	12. REPORT DATE: April 1974
	13. NUMBER OF PAGES: 44
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): N/A	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

N/A

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Helicopter Windshields	Rubbers
Wiper Blade	Acrylic Plastic
Wear	Blade Testing
Abrasion	Synthetics
Polymers	Materials

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The program was undertaken to assess the possible utilization of low friction and/or porous materials in making wiper blades for helicopter plastic windshields. It was, therefore, directed to a search for new materials rather than a comparison of materials in current use. A literature search was made to acquire the most recent information on the theories of wear and abrasion plus any specific literature on wiper blades for plastic windows. A synopsis of wear theory is presented, emphasizing the facets of the theory that apply to this problem. Ideal material characteristics are defined and a list of (CONT)

materials which approach one or more of these characteristics is presented. Some testing of promising materials was done. The test fixture used and the initial results are described. Recommendations for additional materials to be tested are made.

FOREWORD

The work described in this report was performed under Task XI of Contract No. DAAD05-71-C-0422. This report represents a two (2) man-month effort, consequently the scope of work and approach to the problem of windshield abrasion was limited.

The Franklin Institute Research Laboratories wishes to acknowledge the cooperation given by Mr. G. E. Cook and Mr. H. C. Forst of the Applied Physics Branch, U.S. Army Land Warfare Laboratory.

Principal Investigator for the program at the Franklin Institute Research Laboratories was Mr. J. W. Woestman of the Optics and Electronics Laboratory.

ABSTRACT

The program was undertaken to assess the possible utilization of low friction and/or porous materials in making wiper blades for helicopter plastic windshields. It was, therefore, directed to a search for new materials rather than a comparison of materials in current use. A literature search was made to acquire the most recent information on the theories of wear and abrasion plus any specific literature on wiper blades for plastic windows. A synopsis of wear theory is presented, emphasizing the facets of the theory that apply to this problem. Ideal material characteristics are defined and a list of materials which approach one or more of these characteristics is presented. Some testing of promising materials was done. The test fixture used and the initial results are described. Recommendations for additional materials to be tested are made.

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1. INTRODUCTION

The objectives of this program were derived from a need to eliminate or greatly reduce the scratching of plastic windshields on military helicopters due to the abrasive action of windshield wipers. The specific objectives were to analyze the causes and mechanism of wiper blade scratching, to study the relationship of the parameters involved, and to test wipers which were designed to eliminate or at least reduce scratching of acrylic windshields.

2. BACKGROUND

2.1 WINDSHIELD WIPER BLADE

The windshield wiper blades in current use may be represented by the rubber blade supplied for the UH-1 helicopter in service of the U.S. Army. These blades are shaped in an inverted "fir-tree" cross section from a synthetic rubber. They are supported in a metal frame which is flexible to allow the blade edge to contact the curved windshield surface along the entire length of the blade.

2.2 WINDSHIELD

Windshields to be considered are made of acrylic plastic having controlled optical and mechanical characteristics. They are commonly curved to match the envelope of the aircraft in which they are installed. Windshields which have been toughened to have better ballistic and structural properties are made by a "stretching" process. This process results in a surface that is harder than that of ordinary sheet acrylic and such a surface is more resistant to abrasion.

3. CAUSE AND MECHANISM OF WIPER BLADE SCRATCHING

The physical aspects of friction, wear, abrasion and adhesion involve contacting surfaces. The nature of these contacts is so varied and complex, even for a single pair of materials, that no really simple explanation is possible. A study of the literature reveals frequent theoretical explanations for particular materials, but there always appears a lack of sufficient identification of the causes at work to enable a broad application of the theory to a more general class of materials. There is copious literature dealing with specific problems of wear, friction, et cetera, but there is a dearth of literature on the generalized theory. It would be impractical in this effort to sift the former in order to evaluate the appropriateness of the latter. Instead, we have selected the writings of one of the prominent theoreticians, Ernest Rabinowicz of the Massachusetts Institute of Technology. While his theories are not universally accepted, they do appear to have a rational basis and they do tend to be supported by experimental data.

Much of the theory is derived from the measurement of metal to metal and metal to non-metal contacts, and is not directly related to the case of plastic to plastic contact. However, in reviewing the literature, where generalized statements appear to be applicable to all types of materials, that is not solely pertinent to metals, we have considered they will apply to this case of non-metal to non-metal contact.

One of the basic tenets of the theory of wear is that the area of contact is determined by the normal load divided by the penetration hardness. That is, the contact surface increases with loading by deforming either or both materials in a process that involves plastic deformation. This interface, which constitutes the area of contact, provides a proximity of surfaces on an atomic scale and allows adhesive forces to act. The friction between these surfaces is therefore characterized by the surface

energy of the materials. The adhesion of the interfacing surfaces is equated to the sum of the surface energies of the materials in contact plus a third term to account for the mutual surface energy. Denoting the surface energy by γ and the mutual adhesion between materials a and b by Wab, we have

$$Wab = \gamma a + \gamma b - \gamma ab. \tag{1}$$

γab is approximately one-fourth to one-half of γa plus γb. The adhesion forces, according to the theory, are the causative forces of wear. The adhesion of the materials at asperite-junctions ruptures the asperities. This has several effects and these effects can have subsequent and far reaching effects which render the situation difficult to analyze. For example, we have:

a) Transfer of material a to material b. The ruptured junction contains bits of material a joined to material b. Subsequent contact is now possible between a + b and b whereas it was only a and b before.

b) The asperite junction was locally heated by the tension in the adhering materials before rupture. The elevated temperature has now changed the hardness of one or both materials (on a microscopic scale) and thus future junctions will prevail under a new set of parameters.

Other examples could be added to this list, but the point is that the materials encounter an ever-changing set of parameters. The situation is aggravated by introduction of a third body or material, such as a bit of dirt, lubricant or even a monomolecular layer of air.

3.1 RELATIONSHIP OF PARAMETERS AFFECTING WEAR

In this instance, where we are interested in maintaining the optical quality of one of the surfaces, it would seem that we should select materials and condition their surfaces so that there is the lowest probability of these wear processes' getting started. When we do, these same guidelines can be determined for a selection of materials. For example, in Reference 1 on page 35 we have

$$Ar = 2.9\ (Lr[1/Ea + 1/Eb])^{2/3} \tag{2}$$

where

Ar = real area of contact

L = normal force

r = radius of deformed region

Ea = modulus of material a

Eb = modulus of material b

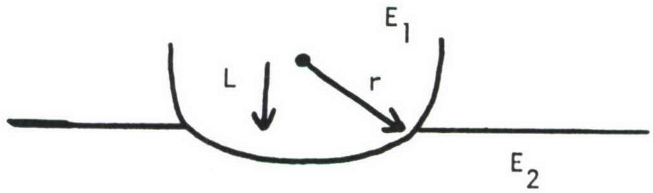

Figure 3-1. Diagram of Contacting Surfaces

This equation applies for only elastic deformation. It shows the relation between Ea and Eb as it affects the contact area and thus the wear. Ea and Eb should be low valued, but since one material, the window, here is polymethyl methacrylate, the other material should have a lower modulus of elasticity. But if it is low by a factor of 5 or so, there is little to be gained by reducing it further. Hence, the wiper material should have a modulus of, say, one-fifth that of acrylic. The modulus of acrylic is between 7,000 and 11,000 psi, so that a wiper material should have a modulus of 1500 psi or so.

Again Reference 1 page 34 states:

$$Ar \gtrsim L/P \tag{3}$$

where

P = penetration hardness (psi)

and the other quantities are already defined. This expression relates to plastic (as opposed to elastic) deformation. Then, to avoid plastic deformation (considered on a microscopic scale, of course), we should use as little loading as possible, but a material with a high value of penetration hardness. Since we are beset with the hardness of the acrylic window, we can at least use the tempered (stretched acrylic) or coat it with a harder material. Both these expedients are being used (Reference 2). We shall see later that the wiper should have a value of P close to that of the window. As a final point, the apparent area of contact will always exceed the real area, Ar, and this should be taken into account in determining the appropriate value for L.

To continue, Reference 1 page 101 refers to the friction-velocity characteristic as shown in Figure 3-2. Some materials show a peak friction at a specific velocity (a) and others show a broad range of velocity over which friction is fairly constant (b). The wiper material should be selected so that the peak or plateau is avoided in order to realize the least friction. Unlike metals, plastic materials have rather widely different friction/velocity characteristics.

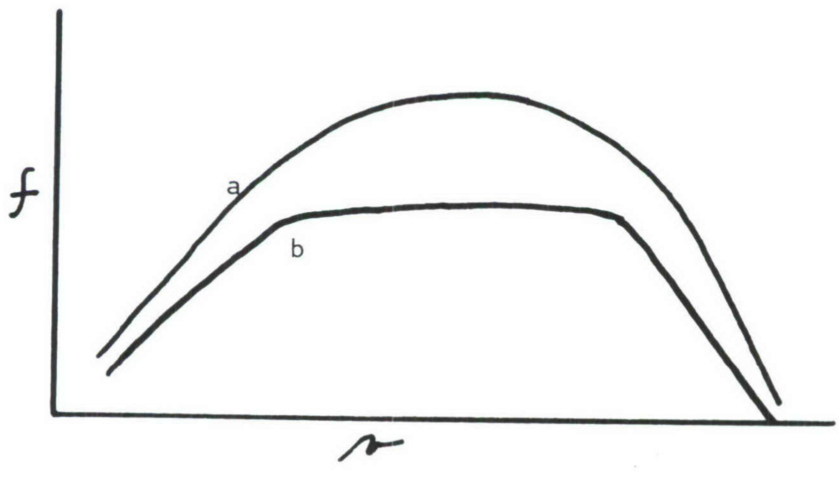

Figure 3-2. Typical Friction Versus Velocity Curves

Reference 1 on page 159 states that there is a minimum load for which loose particle formation occurs. Thus,

$$Lmin = \pi \times 10^{8} \ (Wab)^{2}/P \qquad (4)$$

Low relative adhesion is needed in order to avoid formation of wear particles. Unfortunately values for Wab are difficult to find for two specific materials.

The wear of plastics such as TFE (tetrafluoroethylene) and FEP (fluorinated ethylene propylene) is given by DuPont (Reference 25) as

$$t = KLVT$$

where

t = wear - inches

K = wear factor

L = pressure - psi

V = velocity - fpm

T = time-hours

The value of K for TFE is 2.5×10^{-7}, and for FEP it is somewhat greater than 5×10^{-7}. It can be seen that wear is directly proportional to the pressure and to the velocity. For a given pressure there is a maximum velocity, Vmax which, if exceeded, will greatly increase the rate of wear. Thus the equation has a range of validity determined by the product of pressure and velocity. That is, L x V must be less than some limiting value. For TFE, the limit is given as 1800 (psi x fpm), and for FEP it is 800 when the velocity is 100 fpm.

As statements consistent with theory and intended as design guides, again from Reference 1, we have the following:

page 130 "...if two materials differ in hardness by a ratio R, their wear rate (adhesive) will vary inversely as R^2."

page 151 "...a high value of Wab constitutes the prime condition for strong adhesion of the fragments."

page 182--for minimum wear, soft material should have a hardness less than one-third that of the harder material.

page 173 "...the abrasive wear rate of a surface...is inversely proportional to the hardness of the surface."

page 79 "When non-metals are slid on other materials, the frictional properties tend to be those of the softer material, and the nature of the harder material makes little difference. This is because the harder material, in most cases, becomes covered by particles of the softer one so that eventually our sliding system consists of the softer material sliding on itself."

3.2 MATERIALS OF LOW WEAR CHARACTERISTICS

With these relevant excerpts from the theory we can begin to examine the characteristics of available materials. The wiper material should be softer than the acrylic window but by what factor it is difficult to state. Also, the wiper should not contain hard filler material even though it might be a recommended practice for low bearing friction. Another requirement is for a friction velocity characteristic that does not peak between 6 and 24 inches per second, that is, the estimated range of wiper velocity.

4. MATERIAL SELECTION

A list of wiper materials has been prepared. Materials fall into the general classes of polymers and rubbers and are assumed to be homogeneous. In keeping with the theory the data is listed for unfilled materials. The principal reason for this is that the filler materials are harder than the named materials.

Table 4-1 lists the pertinent characteristics of potentially useful materials. Included are some materials which are related chemically or in their general physical properties. Acrylic plastic is listed as the final item so that its relative properties are available for comparison. Materials are listed in order of hardness, the softest being at the top of the list.

4.1 OPTIMUM MATERIALS

With the help of Table 4-1, it would be interesting to attempt to describe the properties of the ideal material, that is, one that would have minimum wear and/or scratching. Based upon the criteria of Section 5.1, and considering the windshield composed of acrylic material, the ideal wiper material should have properties somewhat as follows:

Hardness	< D70
α compr.	1500 psi
f	< .1
Vmax	300 ft/min
LVmax	800-1800 psi x ft/min

If the wipers are made from TFE or FEP, then the wear for 100 hours of operation can be evaluated from equation (5). The load is given as six pounds and the area of the contact surface measured on the standard wiper blade is 3/64 by 13-7/8 inches. The load, L, is then 9.25 psi.

Table 4-1. Characteristics of Soft Wiper Materials

Material	Hardness	α Yield psi	α Compr. 1 %-psi	f on metal	Elong. % *	Vmax ft/min	LVmax psi x ft/min
Polytetrafluoroethylene (PTFE)	D50-65	2800	600-900	.04	300-600	10-20	1200
Fluorinated ethylene propylene (FEP)	R25, D55	3500	1600	-	300	10	600
Polyvinylidene fluoride Kynar 7200/7201	D65-70	4500-6500	-	-	50-200	-	-
Silastic S-2288	A70-85	700	-	.13	100-250	-	-
Polyamide (Nylon)	R108-111	14,000	5000	.1	-	.002-.4	-
Methyl methacrylate (Acrylic)	M85-105	400,000	15,000	.62	-	-	-

*Elongation is measured as (L - Lo)/Lo where Lo is initial length and L is length at rupture, per ASTM-D638-61T.

The lower velocity at which the wiper runs is approximately 120 feet per minute. Inserting these values into equation (5), it is found that the wear, t, in 100 hours is .028 for TFE and .056 for FEP. These figures apply for the materials rubbing on steel. Wear for rubbing on acrylic should be less.

5. WIPER BLADE TESTING

5.1 WIPER BLADE TEST APPARATUS

The testing of the wiper blades was done on a test apparatus set up in the laboratory. The acrylic test window consisted of a 20 x 30 inch piece of Rohm and Haas plexiglas that was 1/4 inch thick. A fresh piece was used for each sample blade tested.

A heavy duty (truck) wiper motor operating at 12 volts dc was mounted on a plywood base. The acrylic window was held in a frame on the plywood. Pressure on the blade was adjusted to the maximum that the wiper motor and power supply could handle, which was 2-1/2 pounds.

The wiper motor ran at a fixed speed of 96 strokes (back and forth equals two strokes) per minute. The center of the 14-inch blade is approximately 9-3/4 inches from the turning center and the excursion is 80 degrees. Figure 5-1 is a photograph of the test apparatus showing a standard blade on the acrylic plastic sheet. A sample test sheet of the plastic is shown in Figure 5-2.

5.2 WIPER BLADE TESTS

Due to difficulties in obtaining specimens of wiper blades, the number and kinds of tests were restricted. The wiper blades that were available for tests are listed in Table 5-1. Preparation of these sample blades is documented as follows.

5.2.1 Natural Gum Rubber

A strip of natural gum rubber was obtained from Manufactured Rubber Products, Philadelphia. This material was inserted into an aluminum channel as shown in Figure 5-3 to form a cylindrical surface to be used as the wiping surface. The material showed multiple cracks due to tension.

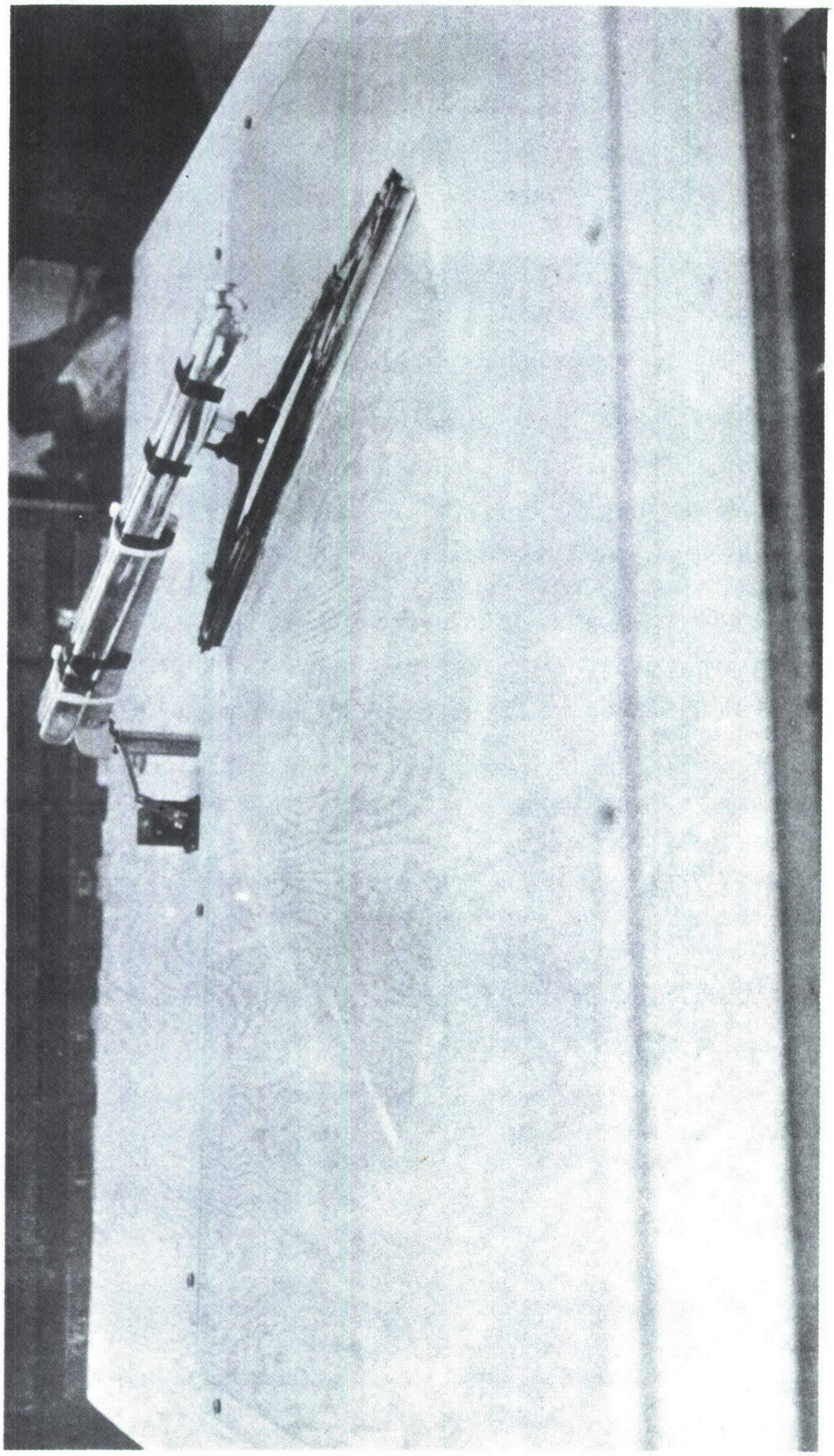

Figure 5-1. Test Apparatus

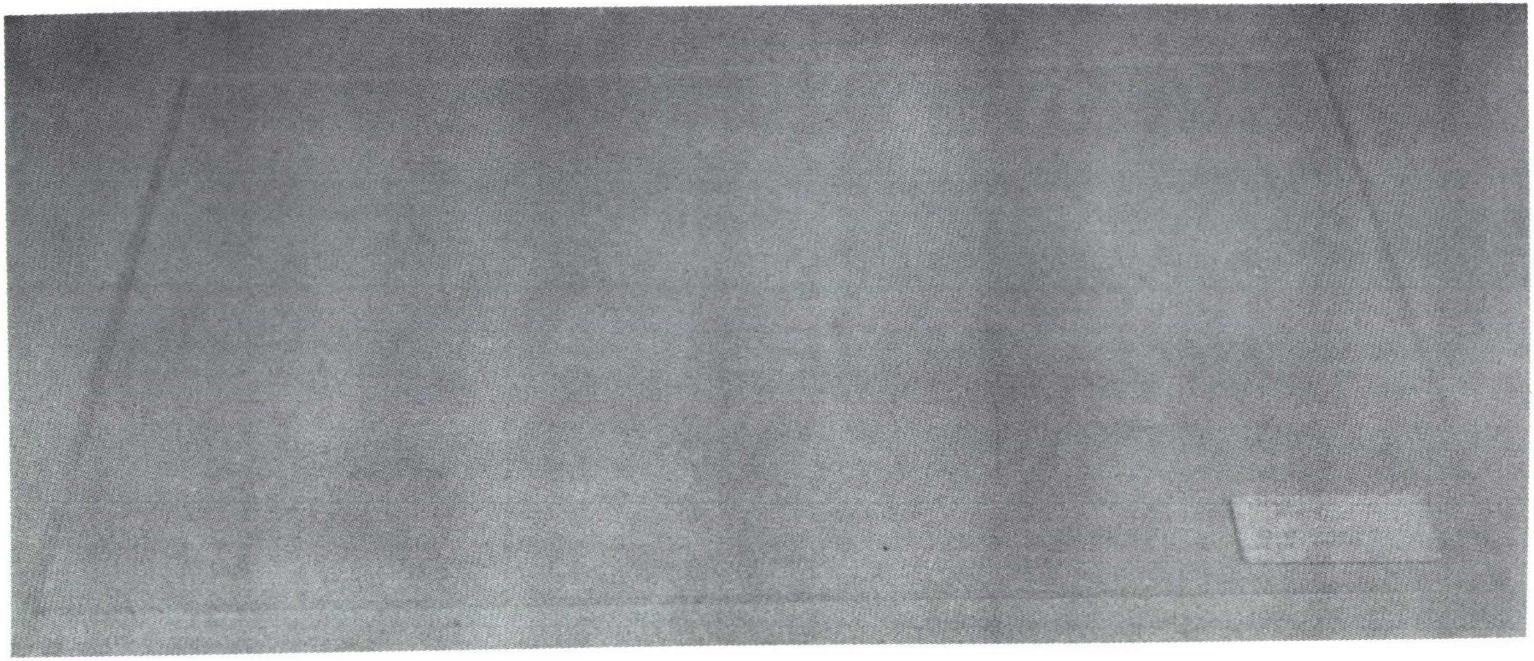

Figure 5-2. Test Acrylic Plastic Sheet

Table 5-1. Wiper Blades Tested

Blade No.	Substrate	Coating	Source
1	Natural Gum Rubber	None	Manufactured Rubber Products (Phila.)
2	Silastic Sponge	Silastic #S-2288	Dow Corning
3	Synthetic Rubber	Unknown	Alco Controls Division Emerson Electric Co.
4	Synthetic Rubber	air-cured polytri-fluoro-ethylene	Achieson Colloids, Inc. (coating)
5	Synthetic Rubber	300° F cured polytrifluoro-ethylene	Achieson Colloids, Inc. (coating)
6	Synthetic Rubber	Graphite and MoS_2	Achieson Colloids, Inc. (coating)

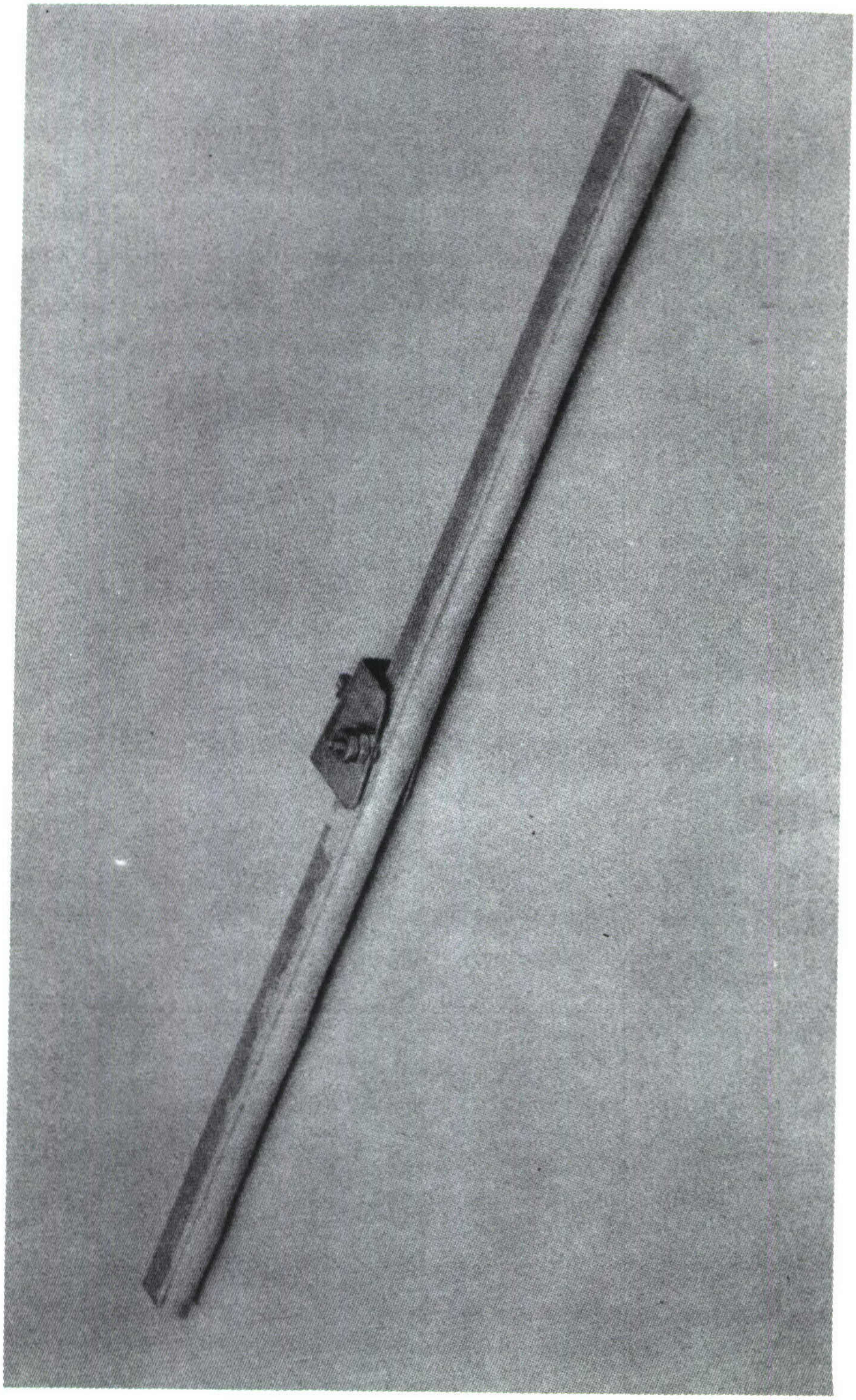

Figure 5-3. Lab-Type Blade Holder

For this reason, it was considered unsuitable for test and no data was taken.

5.2.2 Silastic with Low-Friction Coating

A strip of sponge silastic rubber made by Dow-Corning was obtained. It was inserted into an aluminum channel as shown in Figure 5-3. It was then coated with a silicone dispersion (Dow Corning #S-2288) and cured in an oven in accordance with the manufacturer's procedure. This blade was then tested on the quarter inch thick, 20 x 30 inch piece of stock acrylic. The test was run for 102,416 strokes of the blade at 96 strokes per minute.

5.2.3 Standard Blade

A new replacement blade was run as a control test. The blade is windshield wiper blade refill #XW20973-H14.* The test was run for 100,000 strokes. A photograph of the standard blade in a standard holder is shown in Figure 5-4.

5.2.4 Teflon Coated Blade--Air Cured

This blade was one of seven coated by Achieson Colloids, Incorporated. It was assigned #GP1755D and consists of a standard blade which has been coated with a thin (30-micrometer) layer of PTFE air-cured thermoplastic resin system. It was tested for 100,000 strokes.

5.2.5 Teflon Coated Blade--300° F Cured

The blade was coated by Achieson Colloids, Incorporated and designated with their material Emtalon. This is a thin layer of PTFE 300° F cured thermosetting binder. It was tested for 100,000 strokes.

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*This part number was supplied by Emerson Electric Company as their refill part number for windshield wiper blade XW20257-H14 (Bell P/N 204-070-907-5).

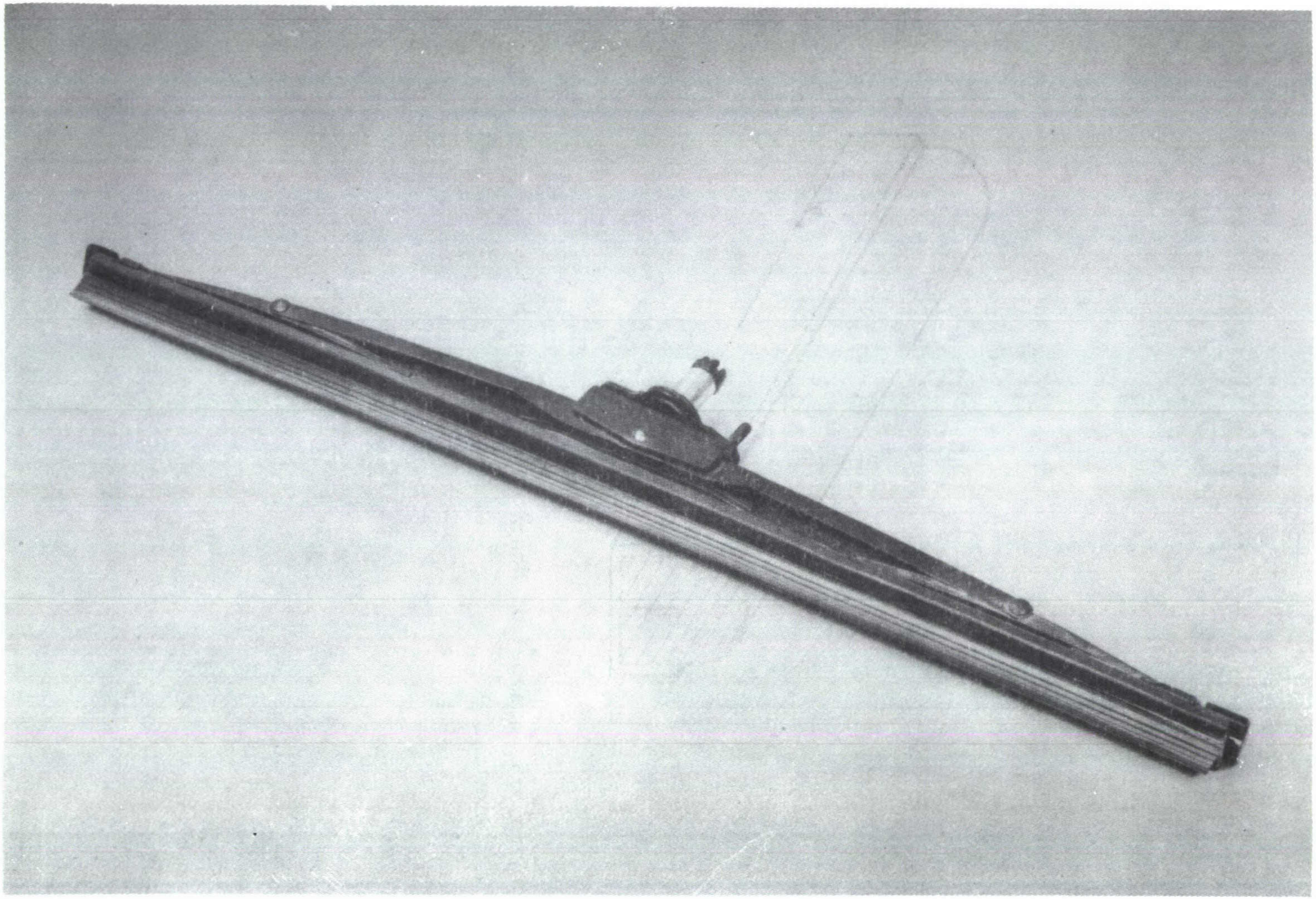

Figure 5-4. Standard Wiper Blade

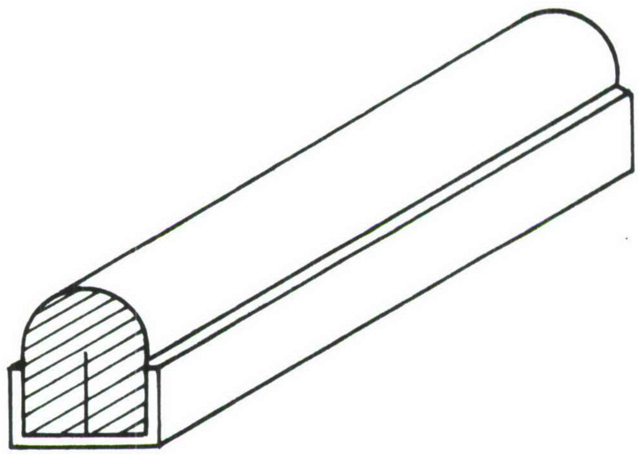

Figure 5-5. Layout of Non-Standard Blade Holder

5.2.6 Graphite and MoS_2 Coated Blade

The blade was coated by Achieson Colloids, Inc. and designated #GP2205. The coating consists of a thin layer of graphite and molybdenum disulfide in a thermoplastic binder that is air-cured. It was also tested for 100,000 strokes.

6. TEST RESULTS

The test results of the sample blades were in many respects similar. The luminous transmittance and specular reflection of the acrylic sample windows were measured before and after the first three tests (5.2.2, 5.2.3, 5.2.4 and 6.4). The results after the tests were within 1% of the results before the tests. The one per cent change noted is not significant. Inspection of the windows after the tests showed that all the blades having a standard blade as substrate generated a fine acrylic powder. While a few scratches were noted, these were attributed to captured dust particles. The wiping action of the rubber blades removed acrylic material but left the surface still very specularly reflecting. Some evidence of grooving is apparent, but the grooves appear highly polished.

The silastic blade, held in the aluminum channel, did not generate any acrylic powder. Scratches appeared to be minor and due to captured dust particles with very little specular grooving being evident.

A close examination of the coated rubber blades revealed the coating was removed from the blade edges but not more than a few mils back from the edges.

7. CONCLUSIONS AND RECOMMENDATIONS

In reviewing the results of the study, soft plastic materials of low friction such as polytetrafluoroethylene and its related variations appear to be applicable to the problem of scratch-free wiper action. Presently used materials, which are essentially synthetic rubbers with thin anti-friction coatings, are less than optimum according to the theories of wear and abrasion. The operational factors of pressure, wiping velocity and material hardness should be optimized for any new wiper material to a greater extent than appears to have been done for the rubber wiper blades now in service. In addition, there may be a need for other modifications to the wiper system in order to utilize softer materials. These other modifications might include means to hold the wiper blade in contact with the window surface at a lower pressure but still prevent uplifting by the wind, a different speed of blade movement or a different maintenance procedure.

In regard to the results of the tests, it is concluded that the TFE coatings were much too thin. The TFE wore off rapidly and reduced the remainder of the test to the rubber substrate contacting the acrylic. The action of the silastic blade is believed to be indicative of the performance of a blade with an adequate thickness of TFE. It was unfortunate that a thick enough coating of TFE could not be obtained for this program.

As the consequence of these conclusions, it is recommended that further attention be given to wiper blade materials in the context of the wear theory presented in this report and that further consideration be given to the window wiping system in the context of using new materials for which the system should be compatible.

Further attention must be given to materials because it was possible to obtain only a few sample materials for this program. Not only should

known materials with suitable characteristics be obtained for evaluation, but it may even be possible to synthesize new materials having nearly ideal characteristics. Since the materials are manufactured in bulk by one company and formed into products by another, it is difficult to obtain small quantities of material in a specific form. Consequently, it is recommended that a follow-on evaluation of materials be structured to support the special efforts that the producers will require.

In order to properly utilize softer materials in the wiper blades, the wiper system will have to be tailored to their characteristics. The wiper must be designed to wear faster than the plastic window by a greater factor than occurs with the present system. In order to obtain long duration service of the wiper as well as of the window, it will be necessary to lower the pressure of the blade against the window and to change the method of maintaining blade contact with the window under wind loading. It may also be necessary to change the velocity of the blade to optimize wear. Finally, the maintenance procedure, time to replace blades and care of blades and windows may require modification. Because of these new conditions, an optimization study of the wiper system to use new wiper blade materials is recommended.

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